GEOLOGICAL INVESTIGATION IN THE BYGLANDSFJORDEN–GYVATN AREA

THE PRECAMBRIAN ROCKS OF THE TELEMARK AREA IN SOUTH CENTRAL NORWAY. NO IX

by

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ABSTRACT

The area consists of Precambrian migmatitic gneisses in which a group of banded gneisses (migmatitic gneisses, sensu stricto) and a group of granite gneisses have been distinguished. Two stages of folding are readily ditinguishable, and it is possible to find some traces of an even older structure (F 1). The F 1 structures were refolded by a system of NW-SE folds (F 2) and later by a system of E-W folds (F 3). The second period of folding produced the most prominent structures, while the third episode is only of minor importance.

INTRODUCTION

The mapped area lies in the north-western part of Aust Agder county in the Setesdal valley, S. Norway (see Location Map Fig. 12). The northern boundary of the area is at 58°40′15″ N and the southern boundary at 58°40′00″ N; in the east the area is bounded by Byglandsfjord lake and in the west by the Skjerka river and Gyvatn lake. The area covered is about 73 km^2.

The Setesdal valley is the major topographical feature; it is U-shaped and, in the area under consideration, about 1.5–3 km wide. Gyvatn

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lake and Sandvatn lake lie in a second U-shaped valley to the west, while the central part of the area is an elevated lake plateau with several ranges of hills rising to 100—150 m.

The area consists exclusively of migmatitic gneisses partially covered by thin layers of Quaternary deposits. All rocks in the area completely recrystallized. For this reason it is impossible to introduce even an approximate stratigraphic sequence.

The area under consideration has not previously been investigated geologically. It forms part of the great Precambrian shield of Southern Norway and belongs to the so called Telemark—Rogaland Region. The mining district of Evje to the south has been described by Barth (1945, 1947) and Bjørlykke (1947).

The present field investigations included geological mapping on a scale of 1 : 25 000, structural measurements, and some megascopic observations of rocks and ore minerals.

This preliminary report contains a description of the rocks and a summary of the structural investigations.

DESCRIPTION OF ROCKS

It seems practical to subdivide all of the migmatic gneisses into two main groups: granite gneisses and banded gneisses. This structural classification is based mainly on the works of Mehnert (1962 p. 97—111) and Polovinkina (1966). Rock descriptions are based largely on megascopic examination and staining techniques (using sodium cobaltinitrite) have been employed to facilitate mineral identification.

Granite gneisses.

Rocks belonging to this group are widespread throughout most of the studied area, and there are several structural types of the granite gneisses.

Homophanic granite gneisses. The term «homophanic texture» was introduced by J. J. Sederholm for those granite gneisses which show random orientation of mineral grains and which are structurally similar to intrusive granites. The present author chooses to use this term instead of the name granite to stress the metamorphic origin of these rocks. Bands, veins, nests, or even completely irregular bodies of homophanic granite gneiss are common in all parts of the area, but

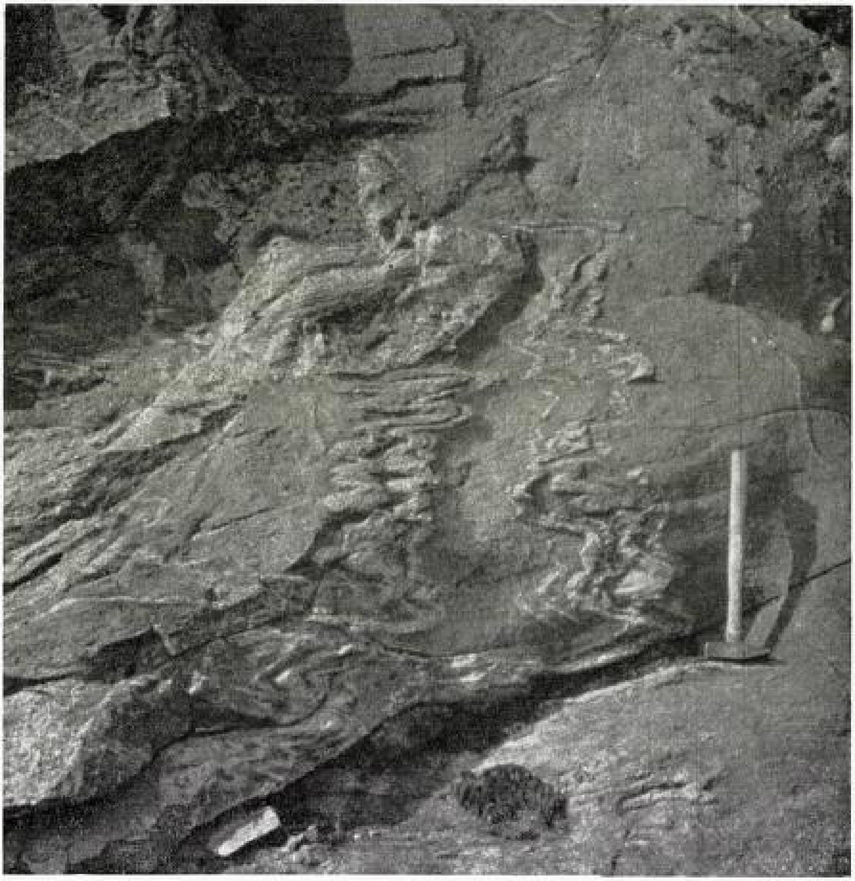

Fig. 1. Mafic inclusion with ptygmatic folding within granite gneisses. About 1.2 km SE of Frøyrak.

bodies large enough to be shown on the present map scale are rather rare. The homophanic granite gneisses are found mainly in the vicinity of Bø. These rocks are fine- to medium-grained, pink, pale rose, or greyish white in colour. The chief mafic constituent is biotite while green to brown-green hornblende plays a minor role. Felsic constituents of these rocks exceed 75 % by volume. Quartz grain boundaries vary from straight to irregular. Undulose extinction is a characteristic feature of the quartz. Plagioclase is an intermediate or basic oligoclase up to andesine. Porphyroblasts of this mineral (up to 6 mm) are fairly uncommon. Sericitization of plagioclases may be present either in the cores or along cleavages. K-feldspars frequently display microcline twinning; microperthitic as well as myrmekitic textures are common. Sphene, magnetite, and zircon are the most notable accessory minerals.

Stained slabs show that quartz and plagioclase are randomly dispersed while K-feldspar is often concentrated in nests and shows a distinct tendency to form porphyroblasts up to 5—7 cm across, and usually displaying tabular habit. They usually contain small inclusions of plagioclase and myrmekite, and commonly show a megascopic perthitic structure. Where K-feldspar porphyroblasts become common, the rock passes into porphyroblastic granite gneiss. The boundary between equigranular and porphyroblastic varieties is always gradational. The porphyroblastic granite gneisses are closely related to the augen gneisses. Both varieties are rare as large rock masses, but small bodies are common in several parts of the area.

Spotted granite gneiss («Forellen-migmatit» or «granite gneiss with Forellen-migmatische struktur», Angel & Staber 1937) contain numerous elongated patches of mafic minerals (mostly hornblende) in a completely homophanic rock matrix, the patches forming a pattern similar to that on the skin of a trout. This type of rock is probably transitional between the homophanic granite gneiss and the laminated granite gneiss. In certain cases where the mafic patches are especially elongated, the rocks display a more or less distinct small scale foliation.

Laminated granite gneisses are widespread. Compared to the homophanic gneisses described above, the laminated gneisses are richer in plagioclase and mafic constituents, especially in biotite which is concentrated along the subparallel laminae. Where the laminae become

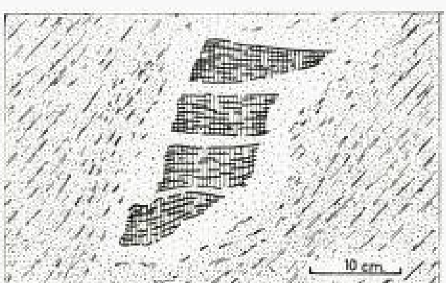

Fig. 2. Mafic inclusion within laminated granite gneiss. The body is broken along structural planes and rimmed by a leucocratic zone. From the ridge between the unnamed lakes at elevations marked 574 m and 593 m.

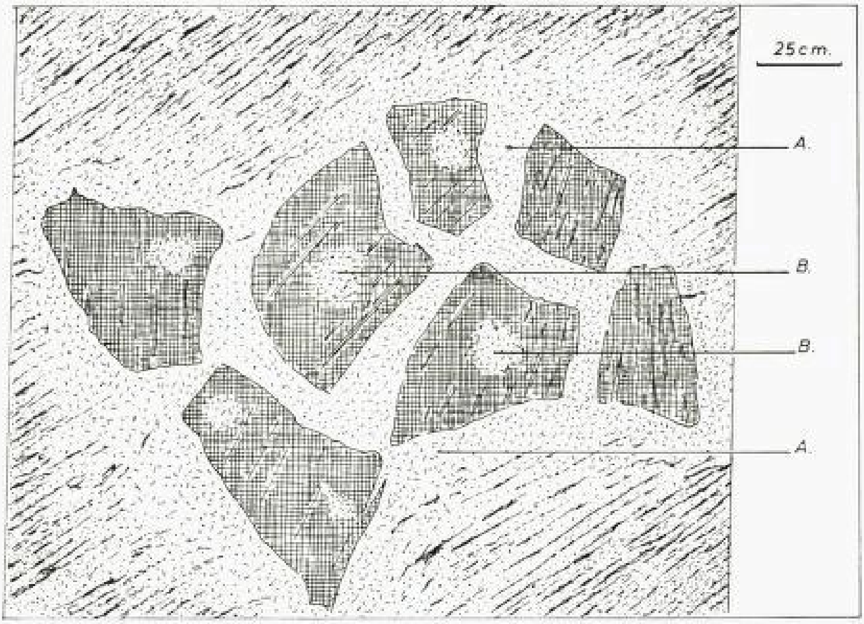

Fig. 3. An agmatite formed by mafic bodies within distinctly laminated granite gneiss. The dark bodies show rather sharp boundaries against the surrounding pegmatite (A), while pegmatite nests (B) inside the dark bodies have gradational boundaries. Roadside exposure 2.2 km SE of Bø.

wider the rock passes into striped gneiss and finally into banded gneiss.

Irregularly shaped, widely spaced dark bodies are common among all varieties of granite gneiss, and it is possible to map zones especially rich in such bodies. The petrographic character of the dark bodies is rather diverse. Most abundant are amphibolites and monomineralic biotite rocks. The last remaining traces of these mafic bodies are skialiths and nebulitic structures in granite gneiss. Granitized mafic inclusions commonly display a distinct folding of ptygmatic character (see Fig. 1), while less strongly granitized bodies were apparently more rigid and formed breccia or agmatite structures (see Figs. 2, 3, 4). Around the dark bodies there are often light aureoles, sometimes pegmatitic. Pegmatites are also commonly present inside the mafic bodies as veins or nests, Figs. 2, 5. Where dark bodies within granite gneisses are numerous and display regular subparallel arrangement, the rock may grade into banded gneiss.

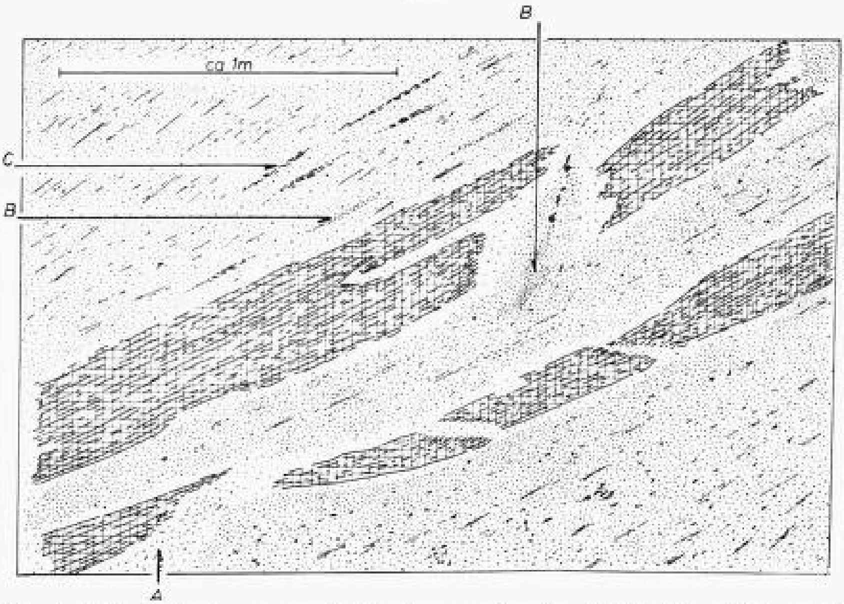

Fig. 4. Mafic inclusions surrounded by leucocratic rims (sahlbands) within granite gneiss. (A) Pegmatite nest with indistinct boundaries. (B) Nebulitic structure formed by dark minerals. (C) Schlieren structure (compare diagram Fig. 8 B). Roadside exposure about 0.4 km to the north of Sines Peninsula.

Fig. 5. Net of pegmatite veins in a dark band of banded gneisses, (light band to the right). Underwater exposure occurring in the southern part of the unnamed lake (565 m).

Banded gneisses.

The banded gneisses are less widespread, tending to predominate in the western and south-western part of the area. Commonly there is no sharp boundary between these groups, and all transitions are possible.

Banded gneisses comprise alternating dark and light coloured bands varying in thickness from several centimetres to several metres. Petrographically, the rocks within the light bands may be similar to rocks of the homophanic granite gneisses, the laminated granite gneisses or (in some areas) the pegmatites.

The rock material in the dark bands is much more diversified. The most strongly granitized members are light- to dark-grey gneisses which are dioritic in character. Their structure ranges from gneissic to almost completely homophanic; the colour is dark grey, much darker than the granite gneisses. Plagioclase is rather abundant but quartz is scarce.

The most widespread type of mafic layers is essentially a finely laminated grey gneiss. These fine-grained plagioclase gneisses commonly show what German geologists have called «Perlen-gneiss-structur». Some rather broad and uniform bands of perlen gneiss extending over distance of some hundred metres have been indicated on the accompanying map. These rocks are usually rich in hornblende and contain relics of amphibolites.

Felsic constituents are quartz and plagioclase (andesine), with K-feldspar in small amounts. There are two variants, one with biotite, the other with hornblende as the main mafic mineral. Biotite-rich types often contain cordierite and secondary muscovite. Hornblende-rich types may gradually pass into an amphibolite by a decrease in quartz content.

Laminae up to 1 cm thick or larger bodies of amphibolite are widespread, but most of them are too small to be shown on the map. These rocks vary from hornblendites to rocks rich in plagioclase. The first type consists almost exclusively of hornblende ($\alpha =$ yellowish green, $\beta =$ green, $\gamma =$ bluish green) with magnetite as an important constituent mineral. Apatite and sphene are common accessories.

Amphibolites are much more common. Hornblende and plagioclase (andesine) constitute the bulk of all specimens examined. The hornblende of these rocks displays various colours from bluish green to brownish green. Sphene, magnetite and apatite are commonly present while quartz and biotite occur in variable amounts. Almost all of the amphibole rocks show distinct traces of biotitization of hornblende. This process is related to a rather strong granitization of the whole area. Biotitization of amphibolites is clearly visible in the vicinity of point 690 m on the map (to the north of Åmdal). This extensive amphibolite is composed of laminae of hornblende with layers of biotite and feldspar. Some parts of the body are almost completely biotitized. There are also numerous nests of epidote which probably originated during the biotitization of the amphibolite.

Pegmatite, aplite and silexite.

Numerous veins, nests or completely irregular bodies of pegmatite, aplite, and silexite cut all other rock types; Figs. 1, 2, 3, 4, 5, 6, 7.

Pegmatites are associated in particular with granite gneisses, but are also developed within mafic inclusions in granite gneisses and within dark layers of banded gneisses including smaller or larger amphibolite bodies. As mentioned above, pegmatites in some places form aureoles around mafic bodies.

Pegmatites rich in K-feldspar are associated with granite gneisses in which they often form veins and nests. When associated with mafic bodies the pegmatites are often pure quartz-plagioclase rocks, commonly forming veins (see Fig. 5), although nests without sharp boundaries can be seen in places. Dark minerals in the pegmatites include both biotite and hornblende. A description of the ore minerals is presented later.

Fine-grained pegmatites with few mafic minerals may grade into very fine-grained aplites. Numerous veins of aplitic character have been observed. These always form small bodies which mostly accompany the granite gneisses. In contrast to the pegmatites, the aplites contain no ore minerals.

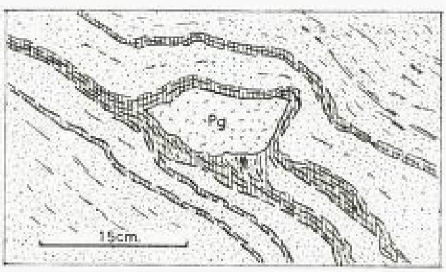

Fig. 6. An irregular pegmatitic body (Pg) within the banded gneisses. From the roadside exposure on the north-east side of the Daleåna river.

With decreasing feldspar content both pegmatites and aplites grade into silexites. Zones, bands and dykes rich in quartz are common. They are grey or bluish grey in colour, and are commonly parallel to the lamination of the surrounding rock. They may however cut across structural planes. A few silexites contain ore minerals.

Ores.

Ores occurring within the area studied are mostly associated with pegmatites. Sulphide-bearing amphibolites have been found only in one road outcrop near Vik creek.

Among the ore-bearing pegmatites, magnetite-bearing rocks are the most widespread. They are common on the east slopes of Vik heii and along the shore of Byglandsfjord lake to the north of Vik creek. In several cases sulphides accompany magnetite. Sulphide-bearing pegmatites are also common. Such rocks are exposed along the road south-east of Tveitå farm. At these same localities hematite-bearing pegmatites have been found. It is possible that the hematite is a product of oxidation of magnetite.

Fragments of rocks containing molybdenite were removed from the cellar of a building at Dale farm during excavation.

The most important occurrences of ore minerals are shown on the accompanying map (Fig. 12).

STRUCTURAL INVESTIGATIONS

Introduction.

The character of the following mesoscopic structures have been studied and measured systematically: folds, faults, veins, several types of «S» surfaces including planes of rock laminations, joint planes, slickenside surfaces. All structural measurements are given in terms of the 360° scale.

The gneisses of the Byglandsfjord–Gyvatn area have undergone polyphase deformation. Two distinct episodes of folding are present, designated F 2 and F 3 together with probably the earliest fold phase F 1, which is of a relict character.

A gneissose structure in granite gneisses and a banded structure in banded gneisses are found to be the dominant planar structures in the area under investigation. The former is a kind of small scale lamination and comprises almost infinite repetition of laminae enriched in biotite. This structure has been developed during the F 2 phase of folding. Micas however have recrystallized mimetically after the earlier fabric, most probably after initial lamination of the supracrust transposed during the F 1 phase of folding. The banded structure is comprised of alternating maphic and granitoid bands of varying thickness from centimetres up to metres and even dozens of metres. This feature is probably of complex origin, probably due to an incomplete metamorphic segregation of the main rock-forming minerals. Moreover some local intrusions of pegmatites subparallel to the foliation of the host rocks are often visible. Regular banded gneisses with straight mafic layers extending over long distances, may suggest that the banding is partly inherited from the bedding of sediments as well as the initial banding of ignous rocks.

Apart from the gneissosity and banded structure, the joint systems are the most pronounced planar structures in the rocks of this area. They have most probably originated after the main metamorphic stage and for that reason will be elaborated separately in a later paper.

Minor folds and related structures.

A. First generation of minor folds — F 1.

Minor folds of F 1 age have been observed almost exclusively in the mafic layers of the banded gneisses. They fold the banding which, in most cases, seems to be inherited from the initial bedding or banding of the rocks. These first generation minor folds are tight or isoclinal. Minor cracks and thrust surfaces commonly accompany these folds (see Figs. 7, 9). Pegmatites have very often intruded the banded gneisses along these thrust planes or cut obliquely across the limbs of folds (see Fig. 7).

Axial directions of the F 1 folds are strongly superimposed by later deformations (F 2 and F 3 phases of folding). The structures which belong to this folding phase are presented in a diagram (see Fig. 11 a).

B. Second generation of minor folds — F 2 and related structures.

Minor folds.

The minor structures associated with the second episode of folding are abundant in the whole area between Byglandsfjorden and Gyvatn. The folds belonging to this phase have deformed earlier minor folds.

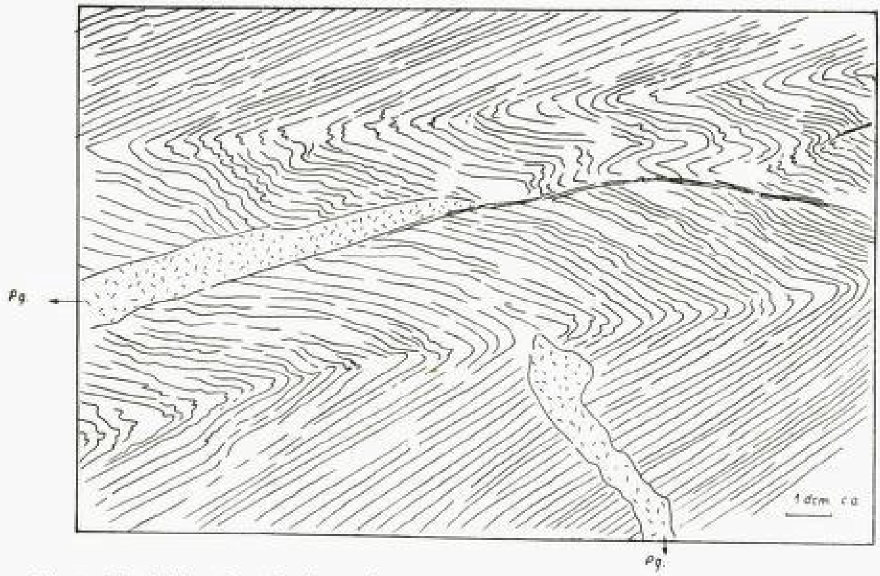

Fig. 7. F 1 fold and axial planar shear. (Pg) pegmatites emplaced along shear surface and across lamination of the rock. About 1.5 km WNW of Sandvikfjellet (721 m).

They may be distinguished from the F 1 folds by their structural style. Second generation minor folds usually show evidence of plastic deformation, the ptygmatic type of folding being common. The fold structures are seldom associated with cracks and thrust planes (see Fig. 1). They are however quite variable, this variations mainly dependent on the (1) physical properties of rock (structure texture and mineral composition) (2) local tectonic environment. It must be stressed that the great mechanical differences between mafic paleosom and leucocratic neosom caused some pecularities in the development of F 2 structures. In places rich in mafic bodies, agmatitic and breccia like structures are clearly associated with the second generation of folds.

Breccia and agmatitic structures.

Some amphibolitic bands and layers (very often completely biotitized) have been fractured due to movement of much more plastic, strongly granitized light-coloured rock material. Amphibolitic bodies have apparently been pulled apart along structural planes (Fig. 3) or along shear planes oblique to the lamination of the rocks (Fig. 4). The second case probably resulted from a stretching of the amhpibolitic bodies while tension acted in the plane of lamination.

The distribution of the mafic bodies is readily studied in the extensive road exposures about 0.4 km to the north of Sines point (Fig. 4). Plots of the orientation of the lamination in the main rock types at this locality are given in Fig. 8 B.

In the area south-west of Hommeknuten several «boudins» of amphibolite surrounded by light-coloured rocks have been observed. In some places the amphibolite layers have apparently been pulled apart into isolated «boudins»[1]) while in others they display a typical necking with alternate thinning and thickening. The amphibolite layers are up to several metres thick and boudinage is developed extensively. These boudins are observed in the limbs of major folds most probably connected with the second episode of folding.

Another type of breccia-like relationship has been observed in the extensive road-cuts about 2 km south-west of Bø. Several dark masses are broken into smaller bodies (from several centimetres to several decimetres in diameter) and dispersed within the granite gneisses, often being surrounded by pegmatite. These fragments were apparently broken along more or less irregular surfaces which usually have no systematic relationship to the internal lamination of the mafic bodies. Later those bodies have been dispersed and rotated. The exposures did not permit measurement for structural analysis. The author believes that these true agmatitic structures are also related to the second generation folds which are clearly evident in nearby crags.

It is believed that where the dark bodies show little evidence of granitization and are relatively rigid, they were dispersed and rotated discordantly within the granitic migma. More strongly granitized bodies show a deformation concordant with that of the surrounding granite gneisses.

Ptygmatic folds and their relationships to agmatitic structures.

The relationship between agmatitic structures and ptygmatic folds is seen in the extensive road-side exposure about 1.2 km to the south-west of Frøyrak. There are several types of mafic enclosures in the granite gneisses. In some parts of this exposure, the rocks display distinct

[1]) Similar structures have been described as so called «Zerrungstexturen» by Mehnert (1962).

«Schollentextures» (term used by K. R. Mehnert 1962). Blocks («Schollen») of mafic rock have been broken and then dispersed in the strongly migmatized and plastic granitic «leucosome». These bodies display various stages of granitization. Less altered by the metasomatic and migmatitic processes are the amphibolites and even monomineralic biotitic rocks. These show evidence of having been rigid bodies during deformation since they are broken up into polygonal blocks with rather sharp boundaries. In the next stage of granitization dark enclosures commonly display venitic structure and are strongly folded (see Fig. 1), rather than broken. In some places it is possible to find some ptygmatic folds which appear as structures resulting from the strong superposition of two or more folding episodes. According to the opinion of several authors such type of ptygmatic folds may be formed even in one folding phase (see H. Ramberg experiments, 1959). The interrelation between axes of ptygmatic folds within the mafic enclosures and the deformation of the surrounding granite gneiss is visible in some places (Fig. 8 A). As the rock becomes more granitic, the outlines of the mafic bodies become indistinct and they may then pass into «schlieren» and finally into nebulitic structures. While granitized xenoliths in several places show random orientation in comparison with the structure of the surrounding granite gneisses, schlieren and nebulitic bodies are more or less concordant. This is clearly visible on the structural diagram of fold axes and poles to lamination for Frøyrak exposures as seen in Fig. 8 A.

This concordance of fold axes in the mafic bodies isolated within granite gneiss may be explained in one of two ways:

1. folding has been generated and controlled by similar forces in all the mafic bodies in spite of the fact that they are isolated from each other by more plastic granitic material;
2. granitization is younger than the folding of the mafic rocks.

The latter point of view is hardly tenable in this case. It is thought that migmatitization processes are syn- or late-kinematic with respect to the F 2 phase respectively and have thus probably been accompanied by tectonic movements.

C. Third generation of minor folds – F 3.

Minor folds of the third generation commonly show evidence of plastic deformation, but tight folds and folds of ptygmatic type do not occur among structures of this episode. Folds of the third generation

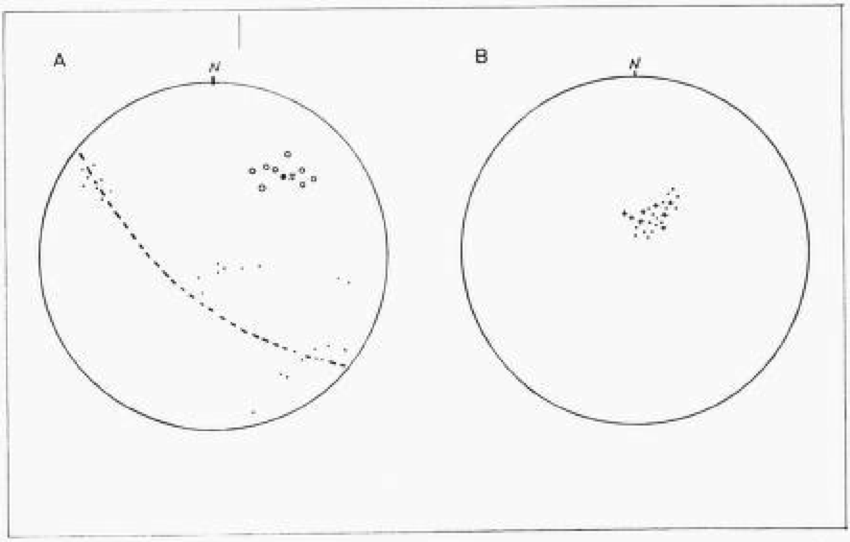

Fig. 8 A. Fold axes (small circles) in venite and poles to lamination planes (dots) in granite gneiss. Pole of girdle marked by black dot. (Lower hemisphere of Wulff net). Exposure 1.2 km SW of Frøyrak (See Fig. 1).

Fig. 8 B. Poles to lamination planes in granite gneisses (dots) and in dark inclusion (crosses). Roadcut about 0.4 km N of Sines peninsula (see Fig. 4).

Fig. 9. Fold structure (probably F 1 fold) dislocated by crestal fracture in banded gneisses, small crag in south Aneknuten (577 m).

are mediumsize structures (several centimetres up to decimetres in amplitude), open in style and symmetrical. Axial direction is constant, E-W up to ESE-WNW. These structures are noticeable fewer in number than F 2 and even F 1. The F 3 structures seem to be of lesser significance than the earlier folding of the F 1 and F 2 phases. The third folding phase has probably been post-migmatitic; however there was probably some pegmatite emplacement during this stage.

D. *Structural control of pegmatitic and aplitic veins and bodies.*

All the rocks in the whole area studied are cut by pegmatitic veins. Many are subparallell to the banding in the host rocks.

In several places «concordant» veins of pegmatites, aplites and silexites pass into discordant veins. The discordant veins have often been intensively folded probably due to differential movement along structural planes (Fig. 10). Small pegmatitic bands in the banded gneisses are in some localities squeezed into boudins.

Some peculiar structures have been observed in certain parts of the banded gneisses, and it is almost impossible to describe them in the conventional terminology of structural geology. They consist of irregular pegmatite bodies surrounded by irregularly folded, dark layers of banded gneiss (Fig. 6). The relationship between pegmatites and agmatitic structures has been described above.

Summing up the above described features we can say that pegmatites were formed mainly during the F 2 tectonism and are strongly involved with this deformation. Some pegmatitic bodies are probably younger.

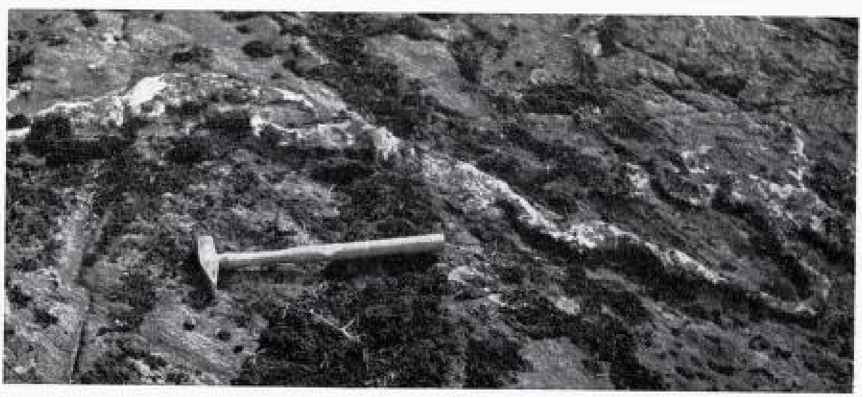

Fig. 10. Pegmatite vein in the banded gneisses, folded probably due to differential movement along lamination planes.

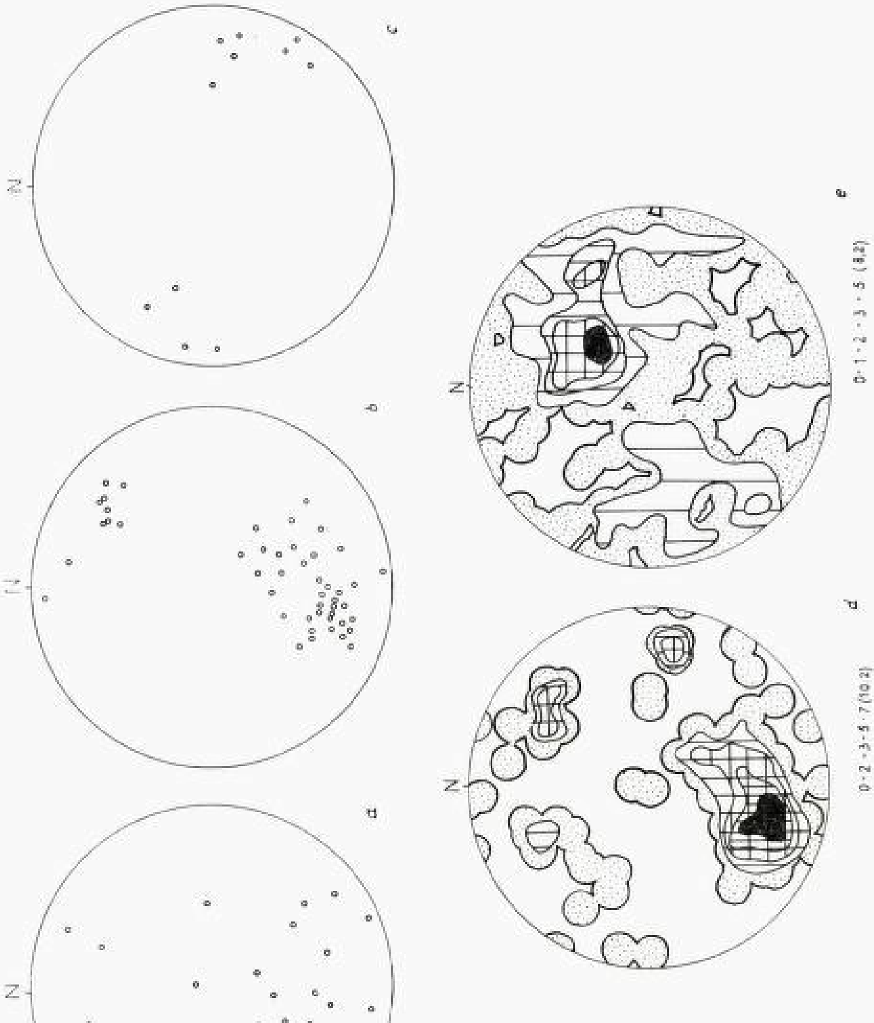

Fig. 11. Structural diagrams from the Byglandsfjorden—Gyvatn area: (a) F 1 fold axes, (b) F 2 fold axes, (c) F 3 fold axes, (d) contour diagram of the fold axes F 1 + F 2 + F 3, (e) contour diagram of the poles of lamination.

Geometric analysis of mesostructures.

During the field work 83 measurements of axes of minor folds and 379 measurements of foliation were made together with a few hundred measurements of joint surfaces. Measurements of joints have not been analysed as yet.

The diagram of F 1 folds (see Fig. 11 a) shows such a strong dispersion of axial directions that it is impossible to speak of a dominant F 1 trend. This dispersion is a consequence of refolding, involving early minor folds, during F 2 and F 3 phases.

The diagram of F 2 fold axes (see Fig. 11 b) shows a much clearer pattern. Most of the F 2 minor fold axes plunge toward SSW, S and SSE at an intermediate angle. A lesser concentration of plots around NNE is also clearly visible. This pattern of distribution of fold axes may be explained as an effect of superposition of the F 2 structures by the later F 3 phase.

The diagram of F 3 folds (see Fig. 11 c) shows a few measurements distributed in the E-ESE and W-WNW directions. All the folds belonging to the F 3 phase have either horizontal or gently plunging axes.

A contour diagram (Fig. 11 d) for the whole area shows two main trends of fold axes. The first system is strongly dispersed and trends

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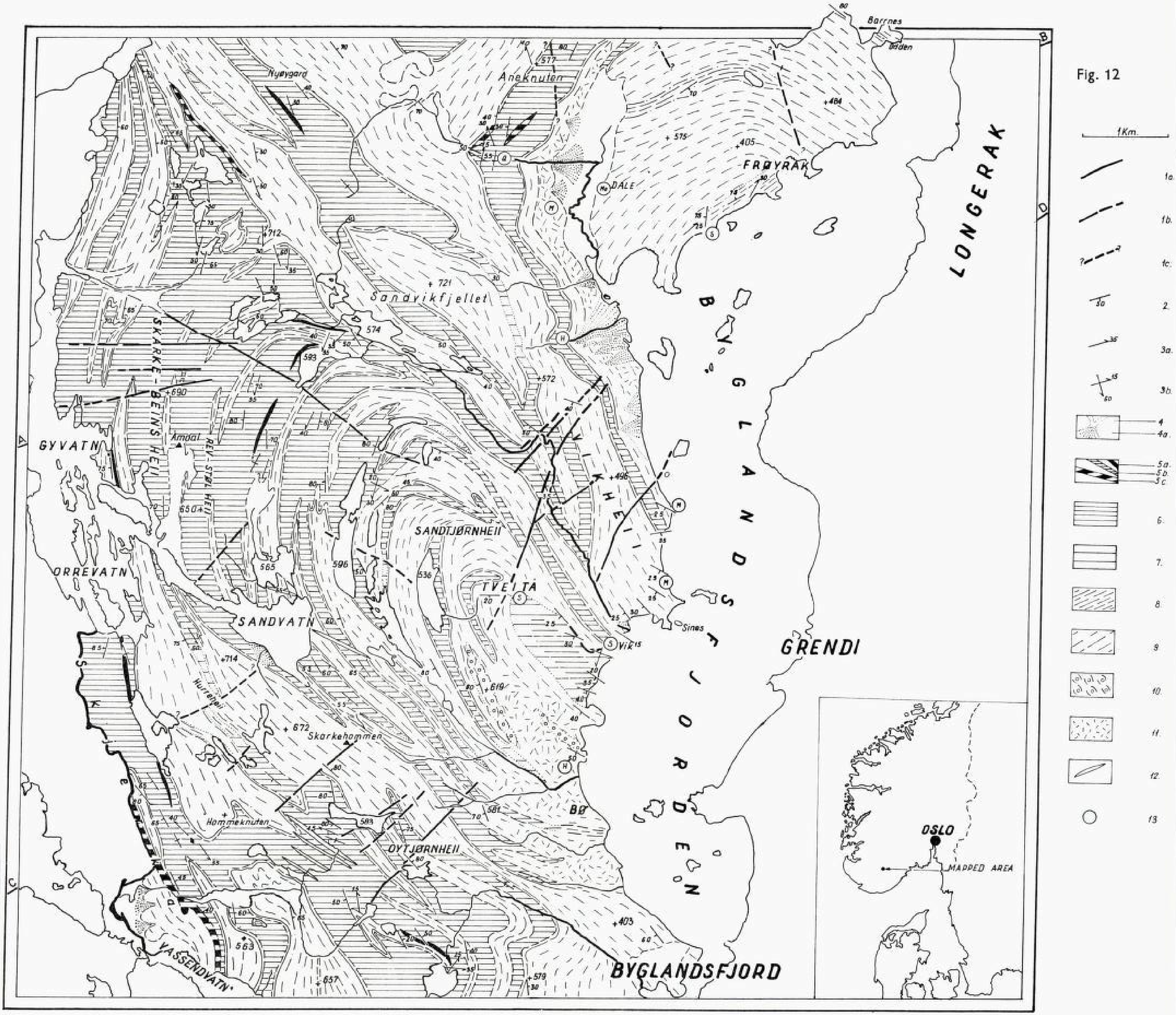
Fig. 12. Geological map of the area between Byglandsfjorden and Gyvatn (Setesdal, S. Norway).

1. Faults. a. definite, b. approximate, c. inferred or concealed.
2. Strike and dip of metamorphic foliation or banding.
3. a. Direction and plunge of minor fold axes or lineation.
   b. Axial directions of cross folds.
4. Quaternary deposits (undifferentiated glacial and fluvioglacial deposits, alluvium. 4a. = talus).
5. a. Amphibolites, b. biotitized amphibolites, c. grey plagioclase gneisses with numerous amphibolite intercalations.
6. Banded gneiss.
7. Light coloured variety of banded gneiss, gradational into granite gneiss.
8. Granite gneiss rich in dark bodies, gradational into banded gneiss.
9. Granite gneiss with laminated, striped or «Forellen-migmatite» structure.
10. Granite gneiss with porphyroblastic texture grading into augen gneisses.
11. Granite gneiss with homophanic and equigranular structure.
12. Larger pegmatite bodies.
13. Mineral occurrences: Mo = Molybdenite, M = Magnetite, H = Hematite, S = Sulphides, Q = Rose quartz.

Fig. 12


LONGERAK
BYGLANDSFJORDEN
GRENDI
BYGLANDSFJORD
FRØYRAK
Barrnes
DALE
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VIKHEII
TVEITA
SANDTJØRNHEII
SANDVATN
SKARKE-BEINS HEII
REV-STØL HEII
Åmdal
GYVATN
ORREVATN
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NNE-SSW to NW-SE with a 10,2 % maximum to the SSW and two weak sub-maxima plunging NNW and NE. The second is an E-W fold system showing a weak maximum plunging gently towards ESE. It should be stressed that fold axes belonging to the E-W system plunge gently in both directions and show little dispersion. The «first system» described above is most probably complex, it consists of F 1 structures rotated during the second period of folding (F 2) together with F 2 folds. The «second E-W system» is that of the F 3 fold episode.

Diagram Fig. 11 b showing poles to lamination surfaces presents an unclear picture, because of the superimposed folding (F 2 and F 3), but it is possible to trace the girdle related to the folding about axes of the F 2 fold system. The other system of folds F 3 (W-E) has probably produced some of the minima on this girdle.

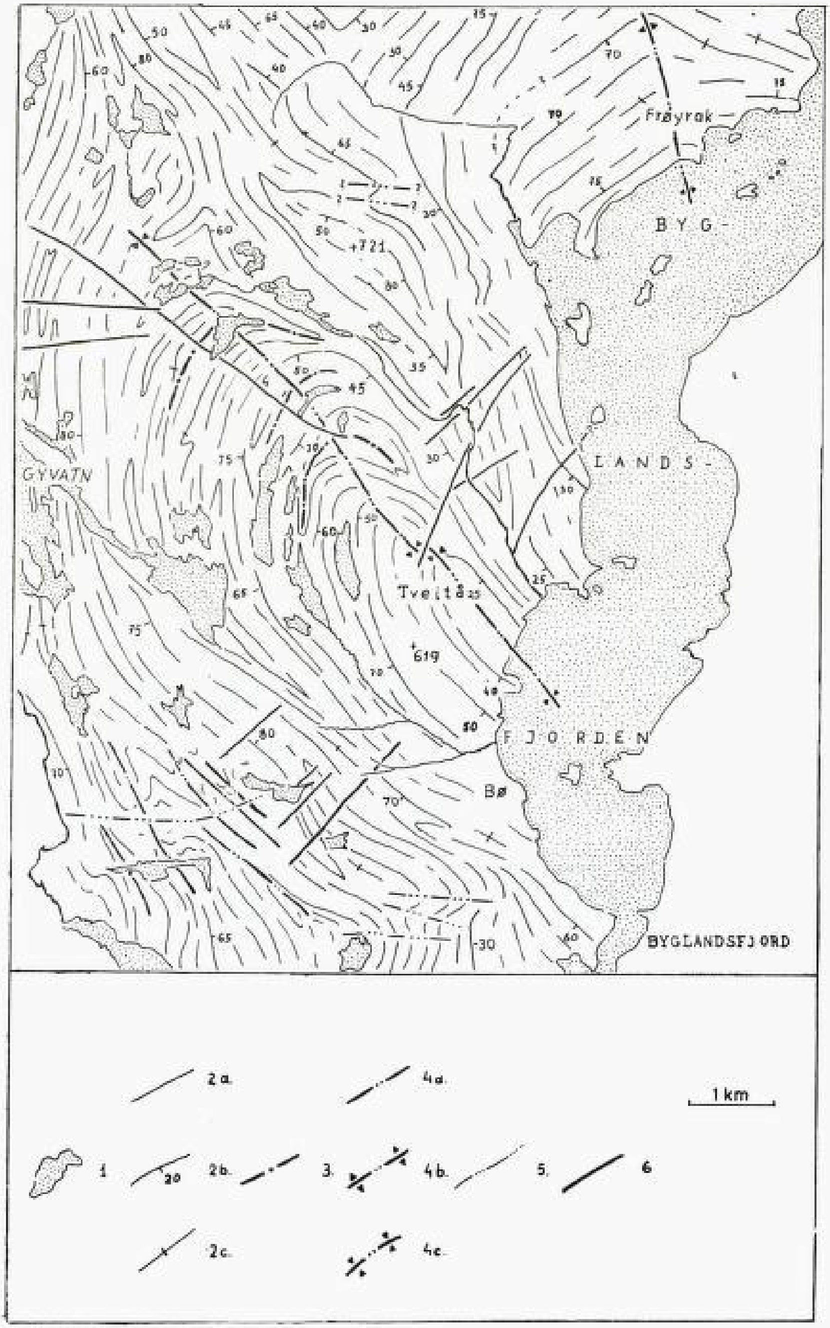
The major structures.

All three periods of folding may be traced on a larger scale by analysis of the outcrop pattern. The minor F 1 fold structures can be traced only as relics. They are best seen in the area to the north-west of the farm Tveitå.

The F 2 structure are dominating in the whole area. They have been studied by a statistical analysis of minor structures as well as a study of the outcrop pattern on the geological map (see Figs. 8, 11, 12, 13). From this the following conclusions have been reached.

The north-eastern part of the area includes a large portion of a big fold structure which appears to be antiformal. This structure is here referred to as the Frøyrak antiform. Observations of minor structures in this domain show that fold axes plunge towards north-north-east, north and north-west at low or intermediate angles. Weak concentrations of plots of fold axes and the rather random orientation of lamination surfaces may be caused by the superposition of F 2 folds and subsequent folding and faulting on earlier F 1 structures. Unfortunately, it is very hard to discern between effects of F 1 and F 2 episodes of deformation especially in the core of the antiform.

The Tveitå synform is situated in the central part of the area. The north-east limb of this synform dips 25°—40° to the south-west, and poles of lamination surfaces along this limb form a distinct concentration on the structural diagram (Fig. 11 e). The western limb of the synform, which has steeper dips, is marked in the diagram by a less distinct


Frøyrak
BYG-
LANDS-
FJORDEN
GYVATN
Tveitå
+721
+619
Bø
BYGLANDSFJORD
1 km
1
2a.
2b.
2c.
3.
4a.
4b.
4c.
5.
6

but clearly visible concentration of plots. The axial place trace of the Tveitå synform can be followed in the narrow zone where the strike direction turns from NNW-SSE to N-S and where the dip angle increases from ca. 25°—40° to 60°—90° (see Fig. 9). Observations from the Tveitå synform show a distinct concentration of axes of minor folds plunging 25°—60° toward the SSE, S and SW with a distinct maximum at SSW on the contour diagram (Fig. 11 d). The axis of the synform plunges approximately SSW at an angle ranging between 35° and 50°, while the trace of the axial plane of the fold trends NW-SE. These data are confirmed by the structural diagram as well as by analysis of the outcrop pattern (Figs. 11, 12, 13).

Both the Frøyrak antiform and the Tveitå synform were probably formed during the second period of folding (F 2). E-W trending folds (F 3 structures) are also present, but they don't play any major role. The two cross sections (Fig. 14) as well as the structural map (Fig. 13) may clarify some of the interrelations between the two major structures.

The southern area which includes the slopes of Hommeknuten, Hurrhei, Oytjørnheii and Svaen up to the Skjerka river as well as northern shores of Vassendvatn, seems to be more complicated, and it is very hard to distinguish clearly any major structures. The NW-SE trending fold axes are strongly dispersed, while the E-W or F 3 folds play a more important role than in the northern areas.

A great dispersion of fold axes belonging to the NW-SE system (F 2) supports the theory that in this southern area F 1 and F 2 fold structures have been strongly affected by superposed F 3 folding or faulting or both.

←

Fig. 13. Geological structures of the area between Byglandsfjorden and Gyvatn (Setesdal, S. Norway).

1. Lakes.
2. a. Trace of metamorphic foliation (dip undefined).
   b. Trace of metamorphic foliation (dip defined by figure).
   c. Trace of metamorphic foliation (vertical).
3. Approximate axial plane trace of major F 1 folds.
4. a. Axial plane trace of F 2 folds.
   b. Axial plane trace of Frøyrak antiform (F 2 fold).
   c. Axial plane trace of Tveitå synform (F 2 fold).
5. Axial plane trace of F 3 folds.
6. Faults.

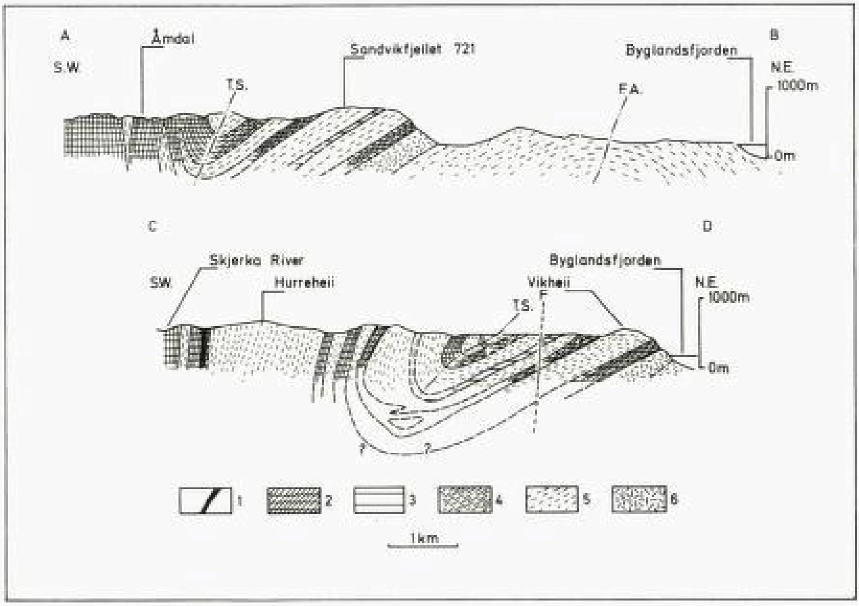


Fig. 14. Cross sections. A—B in the northern part of the area, C—D in the southern part. F.A. = axial plane in the Frøyrak antiform. T.S. = axial plane of the Tveitå synform. F = fault.

1. Amphibolites.
2. Banded gneisses.
3. Light coloured variety of banded gneisses gradational to granite gneisses.
4. Granite gneisses with numerous dark bodies gradational to banded gneisses.
5. Granite gneiss with laminated or striped structure.
6. Homophanic granite gneisses.

Faults.

The most prominent fault direction is NE-SW as seen in the area of Vik heii and Øytjørnheii. Another system trending E-W to ESE-WNW is present in the area of Skarkehommen heii and Revstøl heii. The region to the north of Frøyrak and Dale seems to be affected mostly by faults trending N-S to ESE-WSW.

It is hard to establish even approximately the character of the fault structures. Some faults seem to be younger than the F 3 structures, and these are probably of Caledonian age.

SUMMARY OF THE STRUCTURAL AND METAMORPHIC DEVELOPMENT

Even though examination of the collected material is not yet complete, sufficient data are available to permit a determination of the relationship between tectonic and metamorphic events affecting the rocks of Byglandsfjorden–Gyvatn area. The structural and metamorphic development of this area can be outlined and summarized as follows:

A) The deposition of the sediments. Due to very strong metamorphism it is almost impossible to reconstruct their initial character. These sediments probably consisted of graywackes polymictic sandstones and arkoses while shales and carbonatic rocks have played a subordinate role or even were absent. Within the whole area studied neither kizingite gneisses nor rocks of the marble – lime-silicate kindred have been found.

B) Intrusions or extrusions of basic or ultra basic rocks (now amphibolites, plagioclase gneisses and hornblendites). It also seems probable that some of these rocks may be much younger. R. K. O'Nions, R. D. Morton and H. Baadsgard (1969) have recently reported a synkinematic intrusion of gabbroic sheets from the Bamble Region.

C) The first period of folding (F 1). Some minor folds and some macrostructures belonging to this folding phase are traceable. It is quite impossible to reconstruct any trend of these structures due to the very strong superposition of later deformations. The earliest phase of regional metamorphism – of probable greenschist facies – accompanied this period of folding. The F 1 period of folding may be tentatively regarded as an equivalent of the oldest (NW-SE) folding system reported by Barth (1960) from the Evje–Ivland region.

D) Post F 1 granitisation and anatexis coeval with the stage of maximum of metamorphic grade. Migmatic gneisses of venitic type originated during this stage. These processes continued into the F 2 kinematic phase, and most of the pegmatites are of this age.

E) Late-kinematic phase of F 3. High metamorphic conditions continued up to this stage of deformation, rocks remaining in semiplastic condition.

F) Faulting and jointing which probably developed at least in part, during the Caledonian movements.

Some of the problems concerning the structural and metamorphic development of the Byglandsfjorden–Gyvatn area are solved only tentatively — others still remain unclear. More detailed mapping may help with elucidating some of the structural problems, especially those concerning relationships of the F 1 structures to later deformations. Further petrographical and petrochemical investigations may throw more light on some of the petrogenetical problems.

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References.

ANGEL, F. & STABER, R., 1937. Migmatite der Hochalm Ankogel Gruppe. Tscherm. Min. Petr. Mitt. Bd. 49, p. 117—167.

BARTH, T. F. W., 1945. Geological map of western Sørland. *NGT 25*, 1—10.

— 1947. The nickeliferrous Iveland—Evje amphibolite and its relations. *NGU 168 a*, 1—71.

— 1960. The Iveland—Evje nickeliferrous amphibolite. In Holtedahl, O. (ed.) Geology of Norway. *NGU 208*, 38—41. Oslo.

BJØRLYKKE, H., 1947. Flåt nickel mine. *NGU 168 b*, 1—39.
MEHNERT, K. R., 1962. Zur Systematik der Migmatite. Krystalinikum 1. Prag.
O'NIONS, R. K., MORTON, R. D. and BAADSGARD, H., 1969. Potassium-argon ages from the Bamble sector of the Fennoscandian shield in South Norway. *NGT 49*, 171—190.
POLOVINKINA, JU. IR., 1966. Struktury i tekstury izveirschennych i metamorficsheskich parod Tom II. «Niedra» Moskva 1966.
RAMBERG, H., 1959. Evolution of ptygmatic folding. *NGT 39*, 99—152.

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